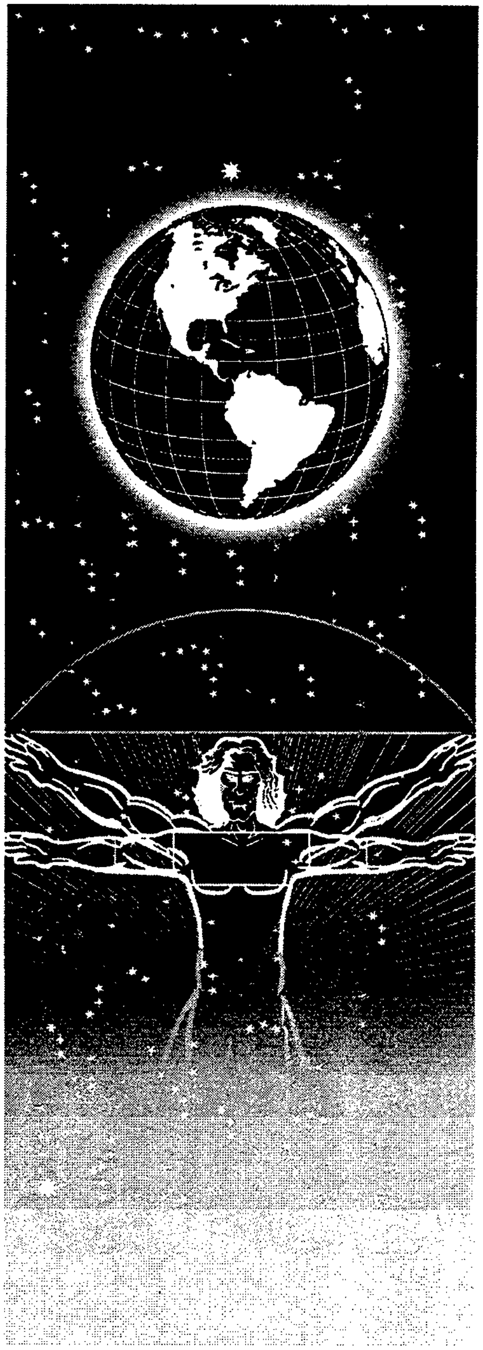
AFRL-HE-BR-TR-1998-0115



UNITED STATES AIR FORCE
RESEARCH LABORATORY

OPTICAL RADIATION: SUSCEPTIBILITY AND COUNTERMEASURES

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December 1998

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This report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Dec 98	Final Report - Sep 92-Nov 97

4. TITLE AND SUBTITLE
Optical Radiation: Susceptibility and Countermeasures - Final Report

5. FUNDING NUMBERS
C - F33615-92-C-0017
PE - 62202F
PR - 7757
TA - B2
WU - 99

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER
TR-00638(FR)

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory, Human Effectiveness Directorate
Directed Energy Bioeffects Division
Optical Radiation Branch
8111 18th Street
Brooks Air Force Base TX 78235-5215

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-HE-BR-TR-1998-0115

11. SUPPLEMENTARY NOTES
Final Report delivered in accordance with Contract Data Item A007.

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The report is organized into sections, with each section corresponding to a main Statement of Work heading and serving as a separate stand-alone document. The main objective of the report is to provide a useful synopsis of research projects or activities that are extensive enough to warrant a name. Accordingly, this report is not a comprehensive listing or journal of all of the activities performed under the Optical Radiation: Susceptibility and Countermeasures contract, as such a document would be largely unusable due to the scope and extent of the projects. For specifics, the project report or published articles should be read. A complete list of all written work, product deliverables, technical reports, journal publications, letters, etc., is included at the end of each section to serve as a guide for those desiring more detail than the synopsized descriptions in this document.

14. SUBJECT TERMS
integrated modeling system; optical injuries; short pulse damage; optical countermeasure systems; scotomas and performance

15. NUMBER OF PAGES
68

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

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Section 1

Model Development, Modification, and Testing

Introduction

During this contract, all of the larger research projects had a modeling component. This is a result of "hypothesis testing" in experimental science – i.e.,, the "model of the phenomena under study" is part of the hypothesis, if not its entirety. While the research areas investigated during this program were broad in scope, they focused primarily upon optical directed energy, the distribution of laser light on the back of the eye, and the resulting occupational and operational impacts of that light. The models ranged from the highly theoretical, such as those developed for the Pulsed Impulsive Kill Laser (PIKL) and Ultra-Short Pulse Laser projects, to those designed for specific military operational activities, such as the Precision Guided Munitions (PGM), Optical Directed Energy (ODE), Directed Optical Radiator (DRAD), and Laser Eye Protection (LEP) projects.

Models, computer or otherwise, were used on all projects at some level. When appropriate, biological surrogates were also used in experimentation, analysis, or both. An informal research team goal was to add models to a standardized palette of software applications developed through years of research and incorporate them into an Integrated Modeling System, or IMS.

The IMS is implemented as the Integrated Laser Personnel Effects Model (ILPEM), an "in-house tool" for laser bioeffects researchers at Armstrong Laboratory. Many smaller projects also had modeling components in the project plans, and some of these models found their way into ILPEM. Significant among them were DRAD and, to a larger extent, the Precision Guided Munitions study that required the addition of real aircraft time/space/position information (TSPI) to the models. A PGM "analysis suite" that leveraged much of ILPEM, LTAMPS, and LTAS – all software development activities originated under the ORS&C contract - resulted. Brief descriptions of the larger modeling and simulation projects follow.

Integrated Laser Personnel Effects Model (ILPEM) Project

TASC Team Leaders:
Mr. Gary Naville (1992-93)
Mr. Norm Barsalou (1993-94)
Ms. Christina Richardson (1994-97)

TASC Team:
Mr. Richard Rybacki
Mr. David August
Dr. Bill Kosnik
Mr. Dave Sober
Mr. Mark Bojarski
Mr. Bryan Lilius
Dr. Brian Lund
Mr. Abel Ruiz
Mr. John Pfalz
Mr. Larry Snyder

USAF Project Leaders:
Capt. David Beneditz (1992-93)
Maj. Louis Harambasic (1993-93)
Capt. Charles Wright (1993-96)
Capt. Howard Gleason (1996-97)

Objective

Develop a user-friendly in-house tool for investigators conducting laser bioeffects research. Specific accomplishments include the development of the underlying ILPEM architecture, an ILPEM Software Design Document, an ILPEM Software Configuration Document, and an ILPEM Software Requirements Document.

The ILPEM project accomplished several major milestones for the USAF. ILPEM resulted in an integrated user environment with pull-down menus, on-line database access, on-line help, and other user-friendly features. ILPEM also brought a more defined approach to the software development work being conducted under the OR: S&C contract by Carnegie-Mellon University, specifically in the Capabilities Maturity Model (CMM). ILPEM was the source of several spin-off software analysis products, to include the Laser Threat and Analysis System (LTAS), the Precision Guided Munitions (PGM) analysis suite, and the Directed Optical Radiator (DRAD) analysis suite. The Laser Threat and Mission Planning System (LTAMPS), a program developed by the Naval Medical Research Institute Detachment at Brooks AFB, also benefited from ILPEM efforts. The ILPEM architecture is shown on the next page.

Laser Threat Analysis System (LTAS)

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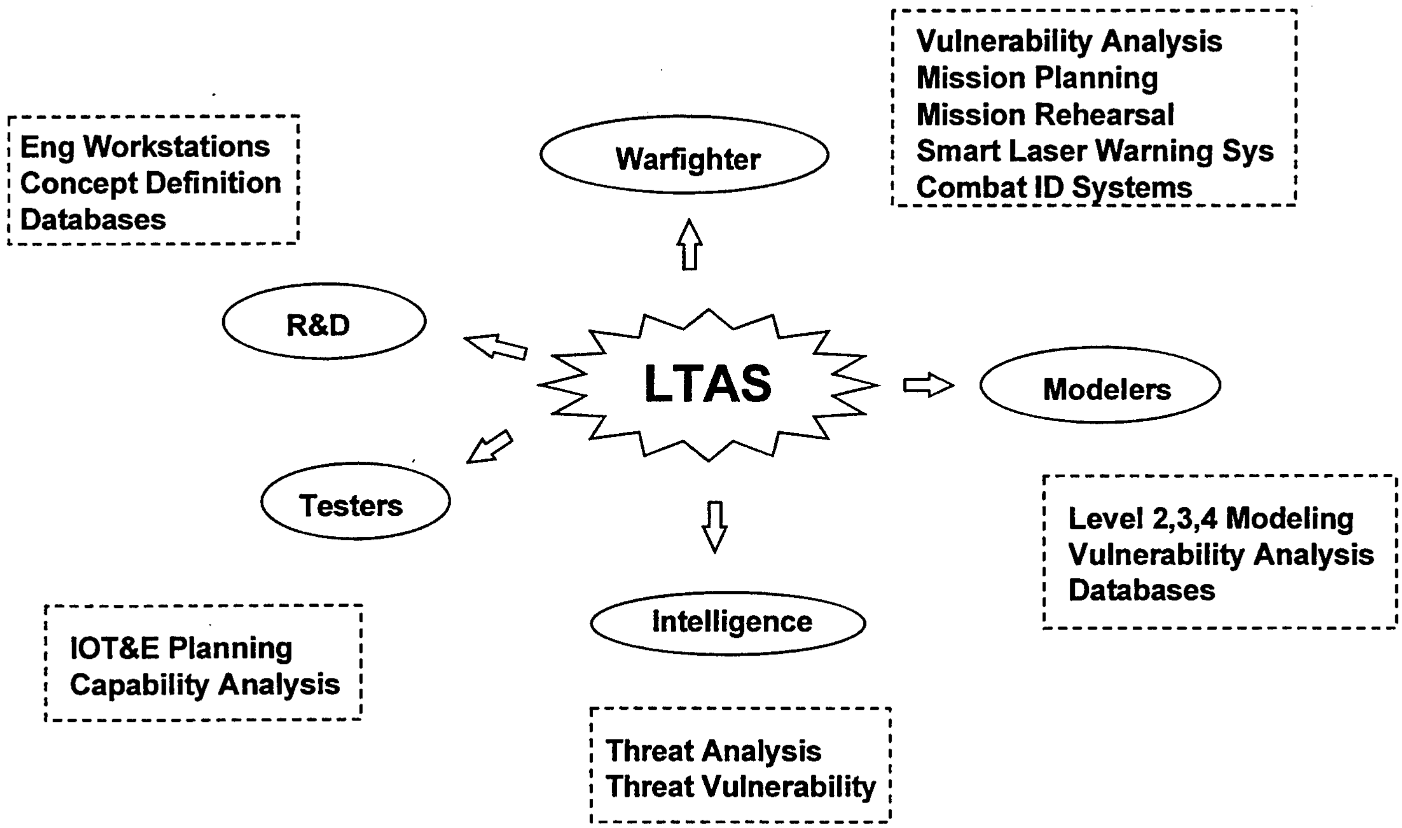
Capt. Charles Wright (1994-96)
Capt. Howard Gleason (1996-97)

The LTAS project had requirements delineated by the intelligence community. Although LTAS was derived from many of the ILPEM source-code modules, it had extensive development requirements unique to itself. The user-interface was designed for persons not conversant in the nuances of lasers, laser propagation, or laser bioeffects. LTAS provides customized applications for intelligence analysts, mission planners, tactics and doctrine developers, and operational mission analysts. LTAS incorporates the use of digital terrain elevation data (DTED), provided by the Defense Mapping Agency, and verified aircraft models, provided by the Joint Munitions Effectiveness Modeling effort. These accurately portray realistic line-of-sight openings between laser threat emitters on the ground and aircraft at altitude by providing line-of-sight determinations into the model aircraft cockpit. LTAS generates threat rings based on the severity of the biological effect of the laser threat parameters under investigation. The use of DTED permits LTAS to analyze any laser threat by incorporating realistic terrain settings, weather, atmospherics, various cockpit canopies and several pilot-related visual tasks. LTAS Version 1.0 was delivered to the Air Intelligence Agency in September 1997, on schedule. The following graphics illustrate the expectations for this tailored computer program that was developed from a sub-set of ILPEM "core software" modules.

LTAS HAS MULTIPLE USES



Any government agency responsible for performing the operational functions depicted above will find **LTAS** to be a usable, comprehensive package. Further development and accommodations for specific requirements can be implemented as necessary.

Laser Threat and Mission Planning System (LTAMPS) Project

TASC Team:
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Ms. Sandy Nguyen
Mr. Dave August
Mr. Bryan Lilius

US Navy Project Leader:
Lt. Cmdr. Michael Reddix

This project grew from an aircraft detection, acquisition and tracking field study conducted by the Naval Aeromedical Research Institute (NAMRI) Detachment 4 and AL/OEO. The Optical Directed Energy project, or ODE, required the alignment of human tracking video with metric aircraft position information. The aircraft time-space-position-information (TSPI) was collected via TACTS (Tactical Air Combat Training System), a telemetry transponder-based TSPI training system similar to the Air Force Air Combat Maneuvering Information System. The objective was to ascertain the susceptibility and vulnerability of ground attack aircraft to hand-held laser threats posed by ground personnel. ODE instrumentation consisted of television video and a recording system that had a GPS receiver injecting a time stamp on each video frame. Data collection of the video with the GPS time stamp was accomplished real-time. Aircraft state vector information was derived post-mission from the TACTS tapes.

The fusion of the aircraft TSPI with the video-based, shooter-derived scoring information was accomplished via a software application that used line-of-sight applications developed for a counter target acquisition study (CTAS) done in 1989. The scoring application enabled an operator to position the aircraft as rendered by the ground TSPI data with the time-stamped video frame collected by the shooter. This resulted in a tracking score for the shooter that characterized the azimuth and elevation pointing error during practice bomb deliveries by F/A-18s at Fallon Naval Air Station, Nevada. The scoring application, due to its ability to work with real-time aircraft TSPI, evolved into a mission playback and analysis package that differed from LTAS in that the engagement geometries were dynamic with respect to time. LTAMPS leveraged many software modules from ILPEM and LTAS, and its unique ability to work with dynamic aircraft-state vector information should be incorporated into the ILPEM core and included in any LTAS enhancements.

Advanced Theoretical Models and Broadband Models

Directed Optical Radiator (DRAD) Project

TASC Team Leaders:
Dr. Ralph Allen
Dr. Larry Mabius
Ms. Christina Richardson

USAF Project Leader:
Capt. Randy Thompson

This project was a study funded by the Army Research and Development Command (ARDEC) to determine the effectiveness of a new broadband optical munition called a Directed Optical Radiator, or DRAD. The study used facilities at the Naval Weapons Center in Crane, Indiana, to gather data. DRAD was a large flash bulb that used shaped-charge solid explosives to produce rapid thermal expansion and excitation of a contained xenon gas mixture. The gas, under heat and pressure of the shaped charge explosion, would emit electromagnetic energy in the infrared and visible spectrum in a relatively short pulse. The major part of the project involved measurement of the spectral-temporal characteristics of the device. A secondary part involved analysis and estimation of the effectiveness of DRAD as an optical munition capable of jamming electro-optical sensors (to include the eye). The DRAD analysis suite was integrated into ILPEM after mathematical development and formulation.

The foundation of the DRAD analysis was the technique developed for analyzing the electro-optical effects produced by nuclear detonations. This technique divided the optical spectrum (270nm – 20000nm) into 14 distinct bands, truncating the number of calculations required and significantly reducing analysis time. The temporal-spectral response of the DRAD detonation was input directly into the nuclear flashblindness model for the estimation of the transient visual effects.

DRAD was determined to be ineffective. The total optical energy output of the device in the visible spectrum was not as high as expected. Because more energy was produced in the infrared spectrum than the visible spectrum, DRAD proved to be a rather inefficient way to produce visible light. The study determined that DRAD was not an effective optical countermeasure for visible wavelengths.

Advanced Sensor Tracking System (ASTS)

TASC Team:
Mr. Randy Kubik
Mr. Larry Snyder
Mr. Gary Naville

USAF Project Leader:
Lt. Col. Robert Cartledge

Objective

To develop data collection and analysis capabilities for the US Army/TACOM Advanced Technology Program (ATP).

The capabilities developed served data collection/analysis requirements for testing in both a Distributed Interactive Simulation (DIS) environment and in field tests. TASC provided expertise on the human vision system and the vision modeling capabilities required during the study. The TASC ***Simulyzer*** was used as the baseline software platform around which other capabilities were developed. ***Simulyzer*** is a proven data display, analysis, and diagnostic tool for use in DIS virtual prototyping applications. It has been developed over the course of multiple government simulation contracts and TASC-funded IRAD projects. The Advanced Technology Program benefited by using an existing data analysis capability and avoided the technical risks that can be associated with an unproven system.

The project was accomplished in three phases.

Phase I	Feasibility Study
Phase II	Proof of Concept
Phase III	Final Implementation

Phase I was executed under the Optical Radiation: Susceptibility and Countermeasures Contract.

Phase I Requirements

During Phase I, TASC interfaced with appropriate TACOM personnel and performed the tasks necessary to satisfy the Statement of Work (SOW) defined in CT (II)-JF-082-94, *Advanced Sensor Tracking System (ASTS).* TASC made recommendations to TACOM on custom ***Simulyzer*** applications, database applications, and field instrumentation and communication requirements. TASC and TACOM revised these requirements to define the planned Phase II development. The final product was a document that included:

- A recommended approach to data analysis, including software development, field instrumentation, and integration
- A review of key decision criteria influencing the approach
- Conceptual diagrams of recommended ***Simulyzer*** applications and report formats
- A work breakdown structure for Phases II and III
- Detailed cost/schedule information for Phase II and projections for Phase III

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Section 2

Optical Radiation Effects on Vision

Precision Guided Munitions Study

In 1993, the Secretary of the Air Force for Acquisitions (SAF/AQRL) asked the Optical Radiation Division of Armstrong Laboratory at Brooks AFB to oversee a multi-service, multi-laboratory project designed to evaluate the effect of low-level laser glare on night delivery of Precision Guided Munitions (PGM) by LANTIRN equipped aircraft. Counter measures to the laser threat were also to be evaluated by testing with and without pilot laser eye protection, and laser glare modeling capabilities were to be developed and experimentally validated. An additional requirement, to provide the FAA with assistance in determining safe laser illumination levels for commercial airliners, was added several months before the scheduled flight-testing. The testing had to meet human use, Air Force Medical Operations Agency, and 46th Test Squadron safety guidelines.

Flights were flown on four different nights. The first flight, during which both the front and rear seat pilots wore eye protection for all laser exposures, was considered a risk reduction mission. Two missions were flown on each of the remaining three nights, for a total of seven missions. Pilots rotated flying with and without eye protection. The aircraft made 92 separate passes past the laser source, and 491 of the 629 recorded laser events were evaluated as "good tracking" opportunities. All test objectives for the PGM flight tests were met, and procedures were developed that will allow future testing at higher exposure levels. The PGM flight test was the first time that the effects of laser illumination on pilots during actual operational flights had been evaluated.

Previous modeling efforts and ground test results had indicated that:

- laser exposure levels approved for this test would not effect heads down munitions delivery
- laser glare effect on the Heads Up Display (HUD) could be partially defeated by increasing the HUD intensity
- the use of laser eye protection would be an effective countermeasure against low-level laser glare.

The PGM flight test confirmed these results in an operational environment. The flight test yielded additional results that could not be obtained from laboratory or ground testing. The results of the operational effects of laser glare are contained in a separate classified report.

One of the primary goals of the PGM test program was to develop a model that could be used to predict the effect of laser glare on pilot ability to accomplish a given mission - a complicated process to model. In addition to basic laser propagation, the model components included the interaction of laser energy with the atmosphere, the aircraft canopy, the pilot's visor or laser eye protection, and the eye. This process is shown in Figure 1. The output of the model is the distribution of laser energy on the back of the retina. A contrast threshold model was also required to predict the masking effect of the laser glare on the visual scene,

as was a model for the post-exposure of temporary flash effects. Another model was required to predict pilot response to the level of target masking. Pilot responses may include a reduction in the ability to acquire and identify a target, as well as the psychological effects that could change a mission or cause it to be aborted. The modeling effort of the PGM test program concentrated on the components that were required to predict which portion of the pilot's view would be blocked by the laser glare. No attempt was made to model temporary flash effects or pilot ability to acquire or detect a target. Initial evaluations were made of pilot responses to varying degrees of laser glare. These results, which include quantitative visual degradation and projected psychological effects, are presented in a separate classified Technical Report.

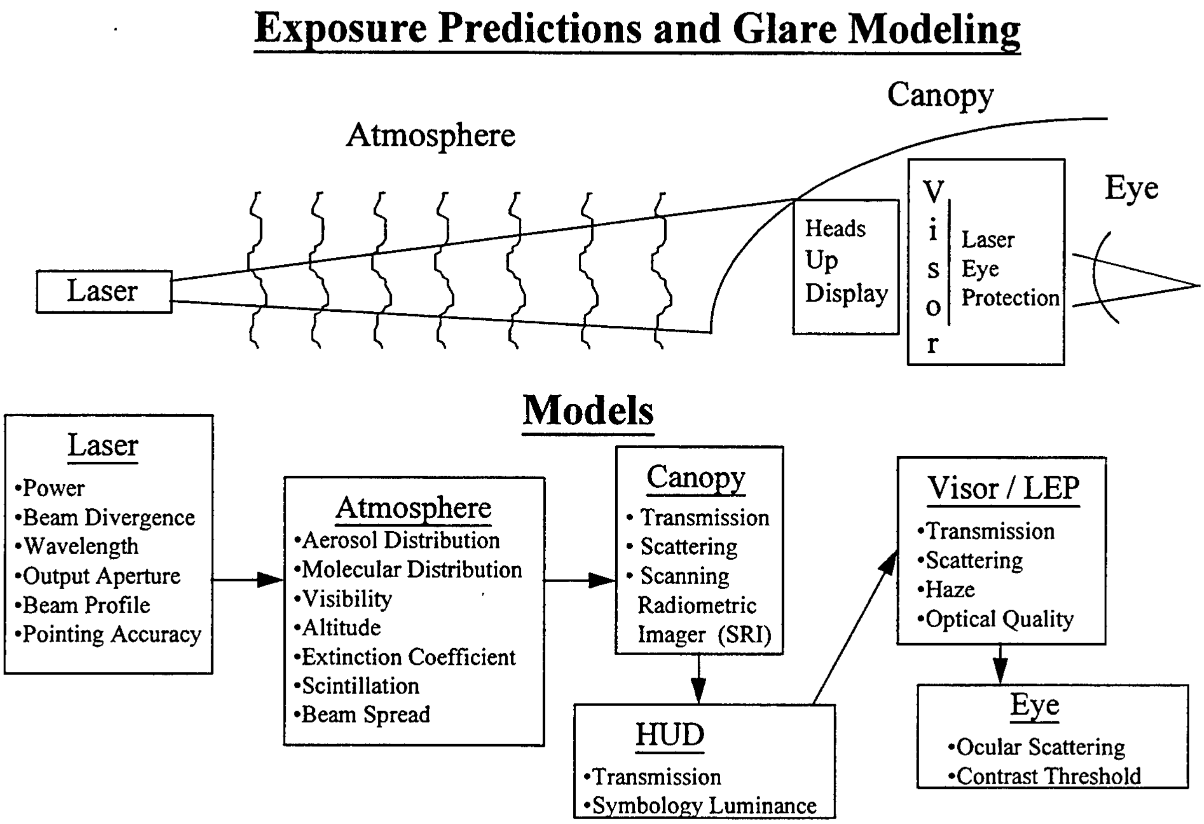

Figure 1: Models used to predict the target masking caused by laser glare. Some of the models are currently under development.

HAVELAW Project

TASC Project Leader:
Dr. Bill Kosnik

USAF Project Leader:
Lt. Col. Bob Cartledge

HAVELAW dealt with the application of lasers as counter-targeting devices for different Air Force mission applications, to include counter-air. In execution, the project required and provided for the refinement of models within ILPEM. Specific sets of requirements emerged and were implemented in ILPEM as a HAVELAW analysis suite that benefited several other projects, to include LTAS and the PGM Study. A classified Technical Report has been submitted for clearance.

Laser Intrusion Denial Study (LIDS)

TASC Project Leader:
Dr. Bill Kosnik

USAF Project Leader:
Lt. Col. Leon McLin

This project was funded by the Defense Nuclear Agency (now Defense Special Weapons Agency) to investigate the possibility of employing less-than- lethal or non-lethal technologies to maintain the security of nuclear materials and weapons storage facilities. This was a human factors study to ascertain the penalties that could be induced upon intruders approaching particular facilities. The experimental goal of this project was to ascertain how long intruders with intentions to violate the integrity of the monitored facilities could be delayed by use of a laser-produced disability glare. The results of this study can be found in "Using Laser Flashblindness to Delay Intrusion" (AL/OE-TR-1994-0129). This was the first study done during this contract that dealt with the concept of lasers as non-lethal devices that had an evaluation assessed with human subjects. Non-lethal applications could have more importance to future programs in laser-personnel susceptibility studies, and have already been applied in the Saber 203 project.

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Section 3

Eye Protection

Introduction

During the period of performance on the *Optical Radiation: Susceptibility and Countermeasures Contract,* several projects had the development of effective aircrew laser eye protection (ALEP) as a principal objective. These projects varied in scope, duration and technology and included the Advanced Aircrew Vision Protection (AAVP), the Wideband Attenuating Reflective Dielectric Out-of-band Visor Evaluation (WARDOVE) and the Advanced Laser filters for Aircrews (ALFA) projects. Polycarbonate absorptive dye technology, dielectric stack technology (DST), and holographic or interferogram reflective technologies were investigated as candidate solutions for incorporation into ALEP visors, goggles or spectacles. The suitability of candidate ALEP devices was investigated with respect to several AF platforms, to include the A-10, F-16, F-15E, and the F-117. Flight tests established the suitability of the ALEP produced for the AAVP project. The WARDOVE and ALFA projects initiated on this contractual effort were continued on a subsequent contract. ALEP devices that progressed to the flight test stage did so only after extensive ground and simulator or weapon system trainer (WST) tests.

Advanced Aircrew Vision Protection (AAVP) Project

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Mr. Mark Awtry
Dr. Jim Dykes

USAF Team:

Lt. Col Bob Cartledge (Project Leader)
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Capt. Steve Troxel
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SrA Brent Eilert

AAVP Background

The AAVP Project was a comprehensive, multi-year technology transition program that evaluated all aspects of absorptive dye technology-based laser protective visors. The AAVP program was funded under Program Element Number 63231F. The project included a manufacturing technology (MANTECH) assessment, Logistics Support Analysis (LSA) Study, and laboratory and flight test evaluations of the state-of-the-art in dye impregnated

polycarbonate protective visors. The project resulted in a definitive interim Technology Transition Document (TTD) that contains all pertinent information for the acquisition of absorptive LEP visors by the Human Systems Center (HSC) Systems Project Office (SPO). TASC supported the AL/OEO team in developing and preparing the interim TTD. TASC responsibilities included defining and developing physical performance requirements, test methods and instruments that contributed to reducing the unit cost of ALEP visors to $100. This simplified and shortened the development and operational qualification time, permitting the acquisition of 4000 visors in 120 days and optimizing the performance of the ALEP. TASC performed and documented a Logistics Support Analysis (LSA) and a Manufacturing Technology (Mantech) study for dye-based ALEP that were included in the TTD.

TASC AAVP Project Objectives

1) Support AL/OEO in developing and preparing the TTD.
2) Acquire LEP samples for evaluation.
3) Define and develop physical requirements, specifications, test methods and instruments to:
    - Ensure mission compatible performance;
    - Reduce life-cycle costs and logistics support;
    - Reduce production response time.
4) Support AL/OEO in testing and evaluating candidate LEP devices.
5) Conduct LSA and Mantech studies for inclusion in the TTD.

The tasks performed and information collected during the AAVP project were included in the TTD. The AAVP Technology Transition Document:

- defined the performance requirements and specifications for LEP;
- recommended test methods for measuring compliance with performance requirements;
- defined and recommended cost reduction improvements in manufacturing technology that increased the speed of production and improved quality;
- defined logistic support requirements;
- recommended an acquisition strategy for reducing costs and maintaining the manufacturing base for production of laser eye protection;
- recommended evaluation methods and manufacturing processes that reduced the logistic support required.

Laboratory and flight test data was provided to support the qualification of the LEP visors as "safe-to-fly" and ready for acquisition and operational use.

Flight evaluations of LEP visors and spectacles were performed.

- F-15E - Day and night operation-Nellis AFB
- F-111 - Day and night operation-Cannon AFB
- F-16 - Day and night operation-Edwards AFB
- A-10- Day and night operation w/ and w/o NVGs-Nellis AFB

Wideband Attenuating Reflective Dielectric Out of Band Visor Evaluation (WARDOVE)

TASC Team:

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WARDOVE Background

The absorptive dye based out-of-band technologies for day and night use that were transitioned in the AAVP program had identified limitations. The WARDOVE project objectives assess an alternative technology to absorptive dye-based LEP that will filter out-of-visible-band light while maintaining high visual quality through the visible spectrum. The WARDOVE project was funded by Congressionally directed funds through Program Elements 64706F and 63231F. The specific objective was to assess the Pilkington Optronics dielectric stack technology in terms of physical and vision performance, flight compatibility and manufacturing process maturity. Since WARDOVE was an ALEP project similar to AAVP, the work performed on this project resembles the research performed under the AAVP project. The evaluations performed on the improved technologies were kept consistent with previous evaluations in order to determine the advantages and disadvantages of using various technologies.

TASC WARDOVE Project Objectives:

- to obtain and evaluate reflective dielectric LEP for use in protecting aircrews from out-of-band lasers
- to obtain and evaluate improved absorptive dye based LEP for protection against out-of-band lasers. The performance of this dye based LEP was used as a comparison for assessing the reflective technology

- to assess the physical performance, to include laser protection, optical quality, reflected optical signature, durability, and ballistic properties of reflective dielectric LEP
- to assess the human factor aspects of reflective dielectric out-of-band LEP, to include cockpit lighting compatibility, Night Vision Goggle (NVG) and NVG lighting compatibility, visual performance, spurious reflections, and narcissus effects.

TASC performed the following tasks under the WARDOVE project:

1) Specified and purchased reflective dielectric LEP for out-of-band protection in visor and spectacle formats.
2) Defined and developed methods for performing meaningful physical assessments of reflective dielectric LEP and used those methods to measure the purchased LEP. The following tests were performed:
   - Angular dependence of transmittance (laser protection and visual performance)
   - Optical performance, to include cosmetic quality, haze, distortion, optical power, and prismatic deviation
   - Durability
   - Ballistic impact resistance.
3) Defined and developed laboratory methods for performing meaningful human factors assessments of reflective dielectric LEP. Assessment methods included:
   - Visual contrast acuity - Regan contrast acuity
   - Stereopsis – Howard Dolman
   - Farnsworth Munsell and pseudo-isochromatic plates
   - Color Symbology Identification (CSI)
   - NVG/ NVG lighting compatibility.
4) Defined and conducted ground tests and Weapon Systems Trainer tests of the reflective dielectric LEP.
5) Provided support for safe-to-fly certification of the reflective dielectric LEP.
6) Prepared a protocol for, arranged, and planned the conduct of flight evaluations of WARDOVE LEP in the F-15E and the F-117 aircraft.

Advanced Laser Filters for Aircrew (ALFA)

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Background

The AL/OEO Aircrew Laser Eye Protection (ALEP) program is a multi-year program to transition ALEP technology from the laboratory to the operational inventory of the USAF. The near-term AL/OEO ALEP program (AAVP) produced an interim Technology Transition Document (TTD) for the transition of a night use, out-of-band ALEP visor and a day use, out-of-band ALEP visor to the Human Systems Center (HSC) for Engineering Manufacturing Development (EMD). A new program was initiated after the AAVP interim TTD was completed. This program was called Advanced Laser Filters for Aircrew (ALFA). The ALFA program was an extension and expansion of the efforts conducted during the AAVP program. The ALFA program was funded under Program Element 63231F, as was the AAVP program. Because of delays in acquisition funding for the purchase of ALEP, the TTD that was prepared for the AAVP program was considered as an interim TTD. This interim TTD was revised and the detailed final reports were prepared documenting the evaluations of absorptive dye out-of band LEP as part of the ALFA program. The ALFA program expanded the evaluation of LEP to include in-band, out-of-band, and combined protection LEP. The LEP technologies assessed in the ALFA program included holographic, rugate and absorbing dye. Samples of in-band LEP were obtained from the Materials Laboratory and the U.S. Navy.

TASC Objectives for ALFA:

- to complete detailed reports for and to revise the AAVP interim TTD
- to evaluate the physical and vision performance of developmental reflective and dye based LEP for in-band protection

- to provide data to guide the technology development programs in holographic and rugate filter LEP
- to establish and expand the capabilities of the AL/OEO laboratories for evaluating in-band LEP
- to perform a Manufacturing Technology Assessment of reflective LEP.

Tasks Performed under the ALFA Project:

- The detailed technical reports of the AAVP program efforts were completed and several revisions of the interim TTD were accomplished.
- Performed initial evaluations of reflective and hybrid (reflective and absorptive) technologies for in- and out-of- band ALEP.
- Performed vision evaluations of reflective and absorptive LEP.
- Expanded the infrastructure, permitting better physical and vision evaluation of LEP.
- The Color Symbology Identification (CSI) was converted to PC control from the former VAX system.
- Improved the laser densitometer to provide more reliable optical density measurements.
- Evaluated holographic and rugate filter spectacles provided by Wright Laboratories for optical quality, laser protection and vision performance.
- Measured temperature dependence and haze of the holographic LEP and used the data to direct the efforts to improve the technology.
- Continued the work that was begun on the Protective Eyewear Automated Test System (PEATS). The goal of this continuing effort is to develop measures of optical performance (particularly haze and distortion) that correlate with human vision performance in flight. Several algorithms for determining the distortion and the optical power from recorded Ronchi patterns were developed and evaluated. Methods of measuring optical performance that are unique to holographic LEP were examined, as were methods that are applicable to dye-based LEP.
- The Automated Mounting and Positioning System (AMPS) was developed. AMPS is a test apparatus that includes a five- axis computer-controlled mount for positioning LEP during measurements. AMPS will facilitate the measurements needed for proper assessment of eye-centered holographic and rugate LEP while reducing the time required to perform many of the physical measurements of LEP. The AMPS hardware design data was documented and provided to WL/MLPJ as part of this jointly funded effort.
- The newly developed scratch resistance tester was used to collect data in support of the WL hardcoating development.
- Performed and documented a Mantech assessment for holographic and dielectric LEP.

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Section 4

Ocular/Dermal/Clothing Damage Due to Optical Radiation

1.318 and 1.356 Mid-IR Threshold Studies

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Objective

To determine the minimum visible lesion threshold exposure parameters in the 11µm – 2.0µm regime for the purposes of establishing safe exposure limits and to determine which ocular structures are at risk for damage from wavelengths in the "Mid-IR band."

This project was motivated by the lack of threshold data for both single and multiple pulses in the 1100 – 2000 nanometer spectrum. This region – notably the 1.318µm line, is of particular interest to the telecommunications industry as glass fibers conduct with minimal attenuation at these wavelengths. Additionally, the Airborne Laser (ABL) Coil laser emits at 1.3µm. As a result of the excellent propagation of these wavelengths through single and multi-mode fibers, research is being conducted to increase the power efficiency and reduce the size and cooling requirements for laser diodes operating at these frequencies. Other applications are also being developed for these diodes.

This knowledge, coupled with the general lack of data in this regime, motivated two threshold studies in this spectral band. Prior to these investigations, the only data collected consisted of a mixture of laser energies at 1.318µm and 1.356µm. The threshold studies conducted under this project investigated both of these lines separately. In accordance with current Air Force guidelines regarding animal use research, these studies initially used Dutch Belted rabbits and then rhesus monkeys as experimental subjects.

It is known that different ocular structures have different optical properties as measured by previous researchers. A seminal study on the optical properties of the rhesus monkey eye was conducted and reported by E.F. Maher in a School of Aerospace Medicine Technical Report from December 1978. That study, "Transmittance and Absorption Coefficients for Ocular Media of the Rhesus Monkey," demonstrated that it was unlikely for any energy to be transmitted through the eye to the retina for wavelengths longer than 1.4µm. At 1.06µm, however, this is definitely not the case. Laser rangefinders are commonplace at 1.06µm and retinal injuries have been associated with the use of these devices. Several animal threshold studies have also established safe exposure parameters for 1.06µm. For wavelengths longer than 1.1µm, the water content of the ocular tissues absorb highly. The issue for this research

project was to determine the occupational safe exposure thresholds for 1.318µm and 1.356µm and to determine which ocular structure was at risk: cornea, lens, or retina.

This project attempted to establish boundaries for the exposure parameters that cause damage to parts of the eye at the two wavelengths of interest. Several exposure sets with varying energy, beam size, and duration were attempted. The results of the studies are summarized in the following table:

Wavelength Threshold	Species	Corneal Threshold	Lens
1.318	Rabbit	175 (154 - 199)	.75[2]
1.318	Rhesus	72 (68 - 81)	1.80[2]
1.356	Rabbit	58 (48 - 72)	2.0[3]
1.356	Rhesus	87 (67 - 102)	5.0[3]
Note: Lens threshold reported as a multiplicative factor of the corneal threshold			

Summary Table of Mid-IR Studies of the Dutch Belted Rabbit and Rhesus Monkey

These studies resulted in new data regarding the relative risk to various ocular structures in the 1.1µm -1.4µm regime. The following conclusions can be drawn from this work:

- For wavelengths less than 1.15µm the transmission characteristics are much the same as 1.06µm, and thereby constitute a retinal hazard.
- For wavelengths between 1.15µm and 1.4µm, *all* ocular structures, to include the cornea, iris, and lens may be affected.
- For wavelengths farther in the IR (greater than 1.4µm) the ocular hazard should be considered to be limited to the cornea due to the relative high absorption of the cornea.

These were single-pulse threshold studies. With the possibility of all ocular structures being at risk in this spectral band, the need exists for multiple pulse studies of varying modulation formats and energies.

Pulsed-Impulsive Kill Laser (PIKL) Project

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Objective

Investigate the ability of high-energy laser pulses to incapacitate live subjects in a manner similar to a blunt trauma injury. This investigation had a secondary objective of incapacitating the subject within two seconds of the PIKL insult.

In recent years, the Army Armament Research, Development, and Engineering Center (ARDEC) at Picatiny Arsenal has sponsored exploratory work on laser applications in unconventional small arms. In 1993 and 1994, ARDEC funded AL/OEO to conduct an experimental program to investigate the viability/feasibility of a man-portable or small crew-served weapon capable of producing incapacitating or lethal effects. This concept is the Pulsed Impulsive Kill Laser (PIKL) that exploits the potential for lasers, under certain conditions, to couple kinetic energy to biological targets. The concept involves laser-induced plasma detonation at the target surface or a violent reactive force caused by tissue (or other material) ablation.

Mission Research Corporation (MRC) of Albuquerque, New Mexico, had previously examined the concept (plasma generation and laser-supported detonation) in theoretical work, and potentially lethal bioeffects were predicted. MRC asserted that the impulse produced on a target irradiated by a short, high-energy laser pulse would be sufficient for use as a weapon. The mission of the PIKL project was to test this assertion and provide insight into the factors that determine the concept's viability as a weapon system.

The PIKL team performed tests of laser/target systems using the High-Energy Laser Systems Test Facility (HELSTF) Pulsed Laser Vulnerability Test System (PLVTS) laser at White Sands Missile Range. The PLVTS laser is a high-energy, repetitively pulsed CO_2 laser with complete beam optics and diagnostic instrumentation. The experiments included two target types: a ballistic target system to measure total impulse, and gel-block targets with embedded pressure sensors. The experiments accumulated data from approximately 92 separate laser firings. For each target type, two surface configurations were used: first, chamois as a skin surrogate, and then Battle Dress Uniform (BDU) fabric over chamois to study the effect of clothing. All tests were videotaped, some with a high speed, charge-coupled device (CCD) camera. Observations included coupling coefficients around 7-10 dyne-seconds (dyne-s) per Joule, and the occurrence of ablation, laser-supported

combustion, and laser-support detonation. Embedded sensors showed internal pressures up to 24 atmospheres (atm).

The interaction of a laser pulse with a target surface produces a rich phenomenology of plasma formation, ablation, combustion and detonation. The PIKL project determined that practical military lasers (man portable or even HMMV portable) are not able to deliver a sufficient impulse to cause concussion or inertial acceleration injury. The MRC theoretical work emphasized the role of plasma formation in the impulsive coupling. Boeing Aerospace Corporation found that plasma shields the target, and that pure ablation gives more effective coupling than plasma formation. Our PIKL experiments found ablation and plasma formation to be roughly equivalent in transforming laser energy to impulse, provided the target is large. If the target is small, the plasma-induced blast wave can escape around the edges and reduce coupling efficiency.

Out of the theoretical and experimental program, several avenues of "Future Work" merit consideration. Whether the PIKL concept is within an order of magnitude of being successful, and hence within reach of technological optimization, depends on the response time of the target tissue. Depending on this value, one of the lasers reviewed may in principle be capable of producing concussion now. A decision on whether to pursue the PIKL concept requires determining the response time of relevant target tissue. Response times can be determined experimentally through acoustic attenuation measurements.

Other injury locations and modalities merit further examination. Information was obtained on impulsive chest injuries, and relevant questions still to be answered include:

- whether the thorax and abdomen are more susceptible than the head to impulsive injury
- whether acoustic, burn, and psychological effects have practical significance
- and whether the eyes and ears constitute significant vulnerabilities.

Determining concussion potential has required extrapolating from mechanical experiments with durations in milliseconds to laser-induced impulses with durations of tens of microseconds. The conclusions concerning concussion were reached using a critical strain criterion for injury. Injuriousness is also influenced by strain rates, so future consideration of thoracic injuries should include an extension of the physical extrapolation modeling presented here to incorporate the effects of thoracic strain rates.

The PIKL Team compiled a "Program Overview Video" (5/20/95) to document research efforts and provide information about the project.

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Section 5

Safety Investigation Program

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Ultrashort Pulse Laser Safety Investigation Program Research Objectives:

1) To determine the maximum permissible exposure limits for the retina using visible and near infrared laser light at five pulse durations between 10 ns and 100 fs.
2) To recommend changes to Air Force (AF INSTRUCTION 48-10) and National Laser Safety (ANSI Z136.1-1993) standards for use of ultrashort laser pulse systems.
3) To determine the damage mechanisms relevant to retinal lesion formation through biophysical phantom experiments, biochemical assays, histopathology, and the wavelength, pulse width and pulse energy dependence of relevant nonlinear optical phenomena.

Ultrashort Pulse (USP) Program

This multidiscipline effort sponsored by the Air Force Office of Scientific Research met several major milestones related to the understanding of the threshold energy level and damage mechanisms required for retinal lesion development with visible ultrashort laser pulses. Single-shot minimum visible lesion (MVL) data was collected for two visible wavelengths and five pulse durations available with the first ultrashort laser pulse system (USP-I). This data set served as one of the primary foundations for the biophysics experimental and modeling efforts. The propagation phenomena that affect retinal lesion development for minimal and superthreshold energy levels were determined. Coordination between propagation working groups extended the usefulness of existing numerical propagation codes to better reflect physical reality. These computer programs previously allowed nonlinear laser pulse propagation with intensities well above the threshold for laser induced breakdown (LIB). After LIB was accounted for in the analysis, the results agreed

more closely with experimental findings. The observation of residual bubbles in-vivo indicated the existence of LIB. The first in-vivo study showing the existence of LIB at MVL energy levels for pulses shorter than 150 fs was completed.

Progress

The program made considerable progress in understanding the thresholds and mechanisms for retinal damage from laser pulses shorter than one nanosecond in duration (i.e., ultrashort laser pulses). The first-ever 1064nm femtosecond (fs) minimum visible lesion (MVL) threshold studies using laser system 2 (USP-II) showed a more significant drop in retinal damage thresholds than those for the visible wavelengths. This was further indication of a new damage mechanism for pulse durations shorter than several nanoseconds (ns). Insight was gained into the role of self-focusing, laser induced breakdown (LIB) and melanin granule heating in changing the threshold for retinal damage and thereby contributing to more severe damage in the superthreshold regime. These studies were complimented by histopathology of exposed retinal tissues using light microscopy and a scanning electron microscope.

The collection and analysis of all single-pulse MVL data for the visible and near-visible spectrum allowed the USP group to make an MPE recommendation for the various safety standards. This recommendation was forwarded by the Air Force to the laser safety and bioeffects communities with the intent to effect a change in the next revision of national and international laser safety standards.

In collaboration with MIT, Duke and the Lübeck Medical Laser Center, the group took part in an analysis of the Optical Coherence Tomography (OCT) study performed in June 1994, that showed real-time trends in (superthreshold) retinal lesion development. Further analysis helped to elucidate the immediate tissue reactions to laser insult that will allow a thorough understanding of retinal laser damage and the possibility of therapeutic effects. Histopathology results were published for comparison.

Prior to the experimental work performed by the USP group on this contract, there were four studies of minimum visible lesion (MVL) induced by sub-nanosecond laser exposures. The contributions made by the joint Air Force/TASC contractor teams during the five-year period established enough relevant information to advocate amending the ANSI Z136.1 standard for sub-nanosecond exposures. As in any circumstance involving the creation of new physical phenomena, albeit laboratory contained, the USP project provided insights into previously unexplored mechanisms of laser tissue damage. The maximum permissible exposure chart on which the ANSI Z136.1 standard is based is shown in Figure 1. This USP research program added six data points in the visible regime and five data points in the near-IR for pulsewidths from below 10 ns down to 100 fs. New maximum permissible exposure limits will be based on these data points.

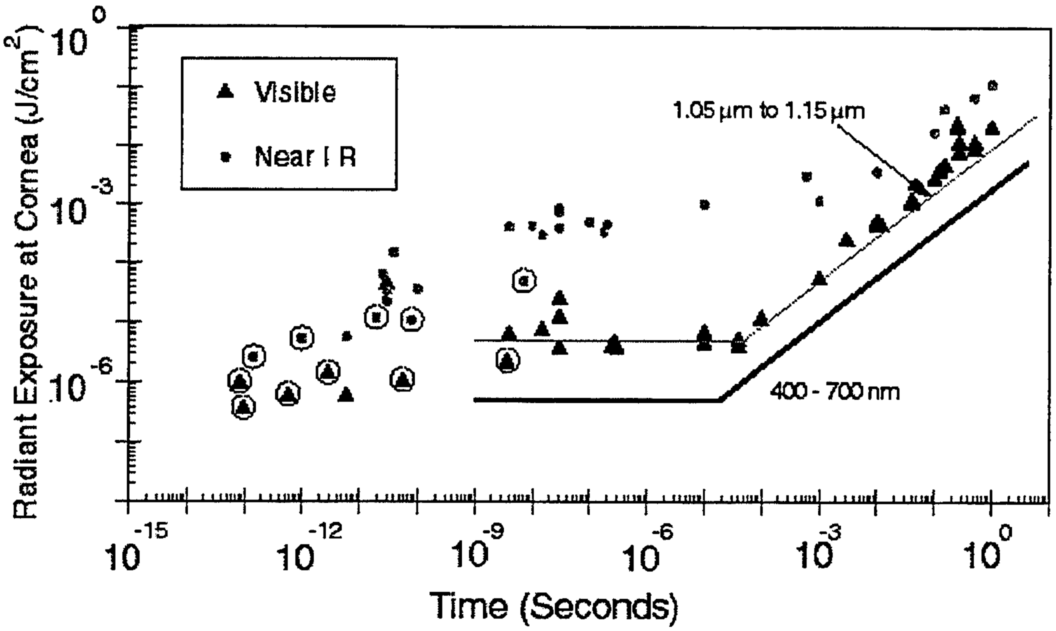

Figure 1: Retinal maximum permissible exposure for ANSI Z136.1-1993. The solid lines indicate the current national standards below which radiant exposure levels are considered safe. The dots represent the database upon which the IR standard is determined, and the circled dots are from the present study. The triangles represent the database upon which the visible standard is determined, and the circled triangles are from the present study.

LIB thresholds were measured and the resulting shock wave and cavitation phenomena were quantified. This allowed the effect LIB has on retinal tissue damage to be determined. The experimental thresholds were matched by theoretical calculations that helped explain the pulse duration and wavelength trends seen in the measurements. Self-focusing was shown to affect the LIB threshold in-vitro. We have hypothesized that the decrease in damage threshold may be in part caused by a decrease in spot size due to self-focusing. This hypothesis needs validation because it is unknown how a smaller spot would change the interaction of the laser pulse with the melanin granules in the retinal pigmented epithelium layer. The melanin granules have dimensions on the order of one micron, and the beam size in the linear case is thought to be near ten microns.

Determining the laser spot size in the eye has been a monumental task for many decades. Analysis of in-vitro and in-vivo LIB thresholds has, for the first time, allowed the extrapolation of the spot size on the retina. Correlating the LIB threshold and the measured spot size in an artificial eye (i.e., in-vitro) with the LIB threshold in the eye of a rhesus monkey (i.e., in-vivo) allows extrapolation of the spot size that created LIB at threshold and hence, the retinal laser spot size.

Four collaborative ultrashort pulse laser research workshops were held with the assistance and support of TASC for the sponsor, AFOSR.

Other Contributions to the Contract

Between October 1992 and June 1997, there were:

- 52 Publications
  - 14 Peer Reviewed
  - 31 Proceedings
  - 6 Technical Reports/TRs
  - 1 Book

- 52 Presentations
  - 31 Presentations w/proceed
  - 14 Presentations w/o proceed
  - 2 Invited
  - 5 Poster

- 48 Abstracts
  - One Patent – (ILSP)

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Section 6

Components/Devices/Equipment Design, Development, and Testing

Introduction

All branches of the Department of Defense are developing laser eye protection devices to protect military personnel from laser hazards and threats during training and combat. Air Force laboratories are conducting development programs to produce and transition holographic and dielectric-holographic LEP in spectacle form. The Naval Air Warfare Center (NAWC) is developing holographic and dielectric-holographic hybrid visors to meet operational requirements of the Navy.

Laser eye protection available to aircrews is limited in terms of protection and lighting compatibility. Armstrong Laboratory conducted the Advanced Aircrew Vision Protection for Out-of-Band Laser (AAVP/OOBL) Program to develop daytime and nighttime visors for protection against laser radiation. The technology that was transitioned for out-of-band (outside of the visible portion of the spectrum) protection uses absorbing organic dyes to block laser light. The relatively wide absorption bands of these dyes are acceptable for use for out-of-band protection, but may not be acceptable for protection against lasers in the visible portion of the spectrum.

LEP technologies that reflect laser light can be made with narrow rejection bands. These reflective filters can be designed to block specific laser lines in the visible portion of the spectrum with minimum loss of visible light. Reflective technology will probably be required for in-band, day/night laser eye protection. Narrow band reflective filters are also more compatible with visual displays and other mission lighting than are the wide-band absorptive dye types of LEP. Additionally, the flexibility to produce filters that can be adjusted or tuned to specific wavelengths at the time of manufacture is much greater with reflective technologies than with absorptive dyes. Reflective technologies include:

- thin film dielectric stack coatings
- rugate coatings
- holographically produced filters
- hybrid filters which use a combination of reflective technologies or a combination of absorptive and reflective technologies.

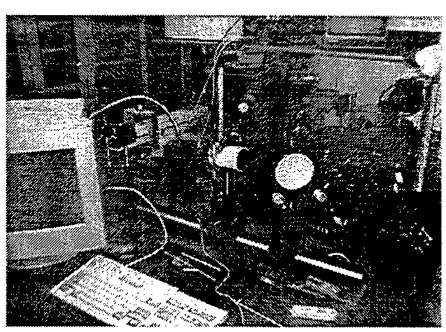
Automated Mounting Positioning System (AMPS)

TASC Team:
Mr. Dave Freeman (Project Leader)
Mr. Bill Brockmeier
Mr. Jerry Hasten

One of the most critical LEP performance parameters is the amount of incident laser light that is transmitted through the LEP device. This performance parameter determines how much laser protection is provided. It is measured in units of optical density (OD) at the specific wavelength of the laser for which protection is required. Absorptive LEP transmittance and optical density are inherently insensitive to the angle of incidence of the laser light. As the angle of incidence of the light increases, the optical density increases only slightly. Thus, absorptive LEP provides some off-axis laser protection. Reflective LEP, on the other hand, is sensitive to the angle of incidence of laser light. Since reflective LEP depends on the interference of light reflected from multiple thin layers of material with different indexes of refraction (in a surface coating or hologram), the optical thickness of the layers is critical. The optical thickness changes with the angle of incidence. This shift can cause significant changes in the protective properties of the LEP. Reflective LEP can provide the required rejection of laser light at normal incidence while providing little or no rejection at angles of incidence not normal to the layers of refractive index variation.

Proper mounting and positioning of laser eye protection (LEP) for testing is critical. Each device must be evaluated at several different positions, and at a number of angles at each position, to ensure that the optical quality and available eye protection are accurately assessed. The need to decrease the time required to manually position the devices and the desire to improve data accuracy generated development of the Automated Mounting and Positioning System (AMPS).

Because the eye rotates during normal viewing, the angular and translational position of the eye pupil changes. To fully assess the laser protection afforded by LEP, measurements must be made in multiple locations and at multiple angles similar to the way in which light might enter the eye. The proper angular and translational positioning of the LEP depends on the format (visor, goggle, spectacle) and the technology used for laser light rejection. AMPS permits the motion of the LEP to be computer-controlled using labview software.



Protective Eyewear Automated Test System (PEATS)

TASC Team:
Mr. Dennis Maier (Project Leader)
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Mr. Dave Freeman
Mr. Jerry Hasten

AF Project Leader:
Lt. Col. Robert Cartledge (1995-1997)
Capt. Curtis Martin (1997 – 1998)

Introduction

Laser Eye Protection (LEP) must have good optical quality and provide protection from lasers. The requirements for optical quality for LEP visors and spectacles are defined in various military specifications and ANSI standards. Under the Optical Radiation contract with Armstrong Laboratory, TASC developed improved methods for measuring and assessing the optical quality of Aircrew Laser Protective Eyewear (ALEP). The Protective Eyewear Automated Test System (PEATS) simplifies and automates the quantitative optical performance measurements of LEP visors and spectacles.

Optical performance parameters measured on LEP devices during the manufacturing process and during acceptance testing include: haze, optical distortion, refractive power, prismatic deviation, cosmetic quality and spectral transmittance in the 200 to 1200 nanometer wavelength region. Spectral transmittance data is used to compute the luminous transmittance, ultraviolet transmittance, optical density at specific laser wavelengths, chromaticity and the neutrality of the LEP. These performance parameters were measured using individual instruments and methods defined in military specifications and ANSI and ASTM standards. Most of the standards, specifications and methods of measurement were developed before personal computers and solid state digital cameras were readily available. Performing the measurements was time and labor intensive. Additionally, some of the performance parameters required subjective judgments and were operator dependent. Other performance parameters and measurement methods were ambiguous or poorly defined in the specifications. The PEATS project was initiated to perform all or a number of the required measurements in an automated manner while reducing the assessment costs for each LEP device by as much as 15% by using locally-developed computer programs.

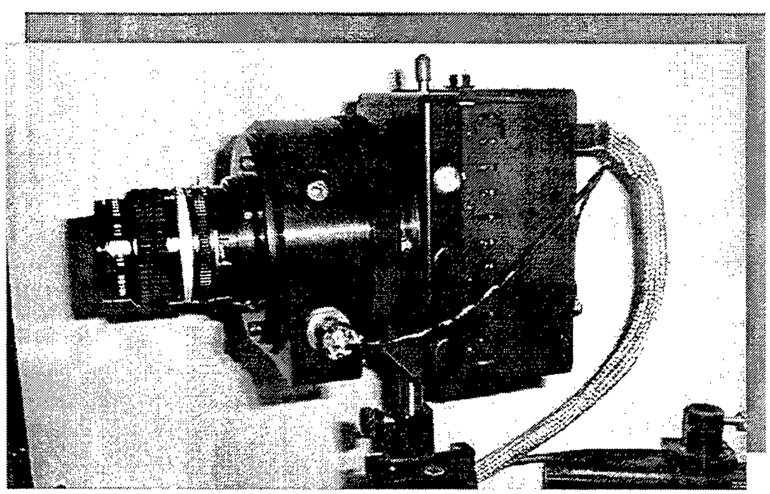
The optical performance parameters measured for LEP are the same parameters needed to assess the quality of other transparencies, such as automobile windshields, aircraft canopies and windscreens, spectacles, fashion eyewear, or any transparent material through which an observer might view a scene. Accordingly, PEATS has a broader application that just measuring LEP.

PEATS Technical Approach

The technical approach was selected based upon the following:

1) Keep the measurement system as simple and inexpensive as possible.
2) Use common instrumentation and hardware to make required optical performance measurements.
3) Make the system rugged and conducive to use in a manufacturing environment.
4) If possible, avoid using lasers to perform measurements.
5) Use white light since transmittance at many wavelengths is one of the measurements required.
6) Provide the system with the required precision, accuracy and resolution to measure optical parameters without making it overly sensitive.
7) Automate the measuring system, to include the aspects of data collection and reduction.
8) Relate or trace system measurements to those made with currently defined methods and instruments.
9) Relate the physical optical performance measures to user visual performance or acceptance.

These considerations and objectives determined the basic components of PEATS. PEATS has a light source, a detector system, a pattern generating system, a spectral dispersing component, optical components for projecting and collecting the light and patterns, a mechanism for holding and positioning the sample, and a means for collecting, processing, storing and displaying the data. The system has sufficient spatial resolution, dynamic range, and spectral response to perform the measurements.



PEATS Setup

A single-pass Ronchi test, similar to the distortion test defined in MIL-V-43511C, was chosen as the basic optical configuration. The layout of the system is shown in Figure 1. The Ronchi test was chosen because it uses inexpensive components, white light, has good sensitivity, and directly relates to existing standards. A single-pass Ronchi test, as opposed to the double pass test defined in MIL-V-43511C, was chosen so that relatively low transmittance samples could be better accommodated. The Ronchi test provides direct measures of distortion and refractive power. Minor alterations of the configuration make it possible to measure prism and haze. The basic components can also be used to measure the spectral transmittance of the sample. A high dynamic range charge coupled device (CCD) camera is used to capture the light patterns transmitted by the system. The image data from the camera is captured and processed by a computer with image processing software.

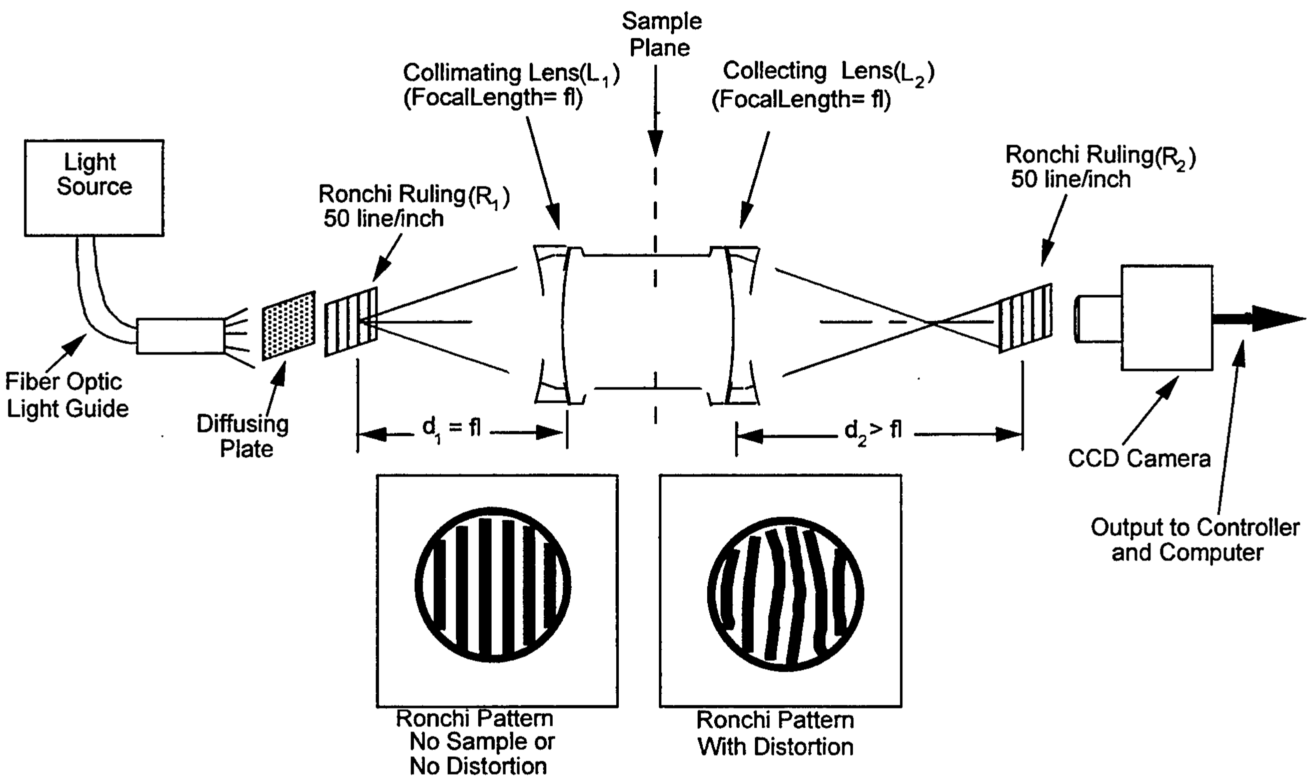


Figure 1: Layout of the single-pass Ronchi test in PEATS

AMPS and PEATS provide the USAF with a way to automate a multitude of laser eye protection physical evaluative tests. The automatic positioner (AMPS) coupled with the automatic optical test system (PEATS) permits timely and consistent evaluation of candidate laser protective eyewear. The individual and combined systems can be applied to commercial production.

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Section 7

Laser Range Surveys and Device Characterizations

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Program 8 is a safety effort initially funded by the Defense Health Program (DHP) in support of operational units of the United States Air Force (USAF). Prior to the *Optical Radiation: Susceptibility and Countermeasures* contract, neither the Armstrong Laboratory Optical Radiation Division (AL/OE) nor its predecessors had done much range survey consultative work. With DHP funding in 1995, AL/OEO organized and initiated an active program to ensure that systems requiring the use of lasers (critical for precision guided munitions and forward air control functions) were safe for use and performed to specification. The proliferation of semi-conductor lasers and light emitting diodes, as well as their relative ease of acquisition by commercial companies, allowed military units to purchase laser-based systems directly off-the-shelf with little or no guidance on the safe and effective deployment of the systems. Program 8 effectively provided guidance in the form of consultative reports and letters that specifically addressed the needs of operational units. Major Commands (MAJCOMS) are now funding work requirements for this program. The Program 8 activity was a new mission area for AL/OEO during the period of performance of the OR: S&C contract.

Five primary categories of work are conducted under this on-going project:

1) Provide technical support by measuring laser system parameters to establish ocular/skin hazard safety guidance for operational units.
2) Conduct laser range safety surveys to verify that ranges are operating safely under military guidelines: provide recommendations to insure the safety of personnel using the ranges.
3) Measure previously uncharacterized laser system output parameters for use in hazard analyses.

4) Evaluate and establish guidelines to minimize flight hazards associated with the use of lasers in commercial entertainment or advertising.
5) Complete special projects or activities to support and enhance the four previously listed areas.

Significant Accomplishments

- Establishment and organization of a central database to serve as a repository of all USAF laser safety information as collected by AL/OEO and TASC personnel. This database, operating on desktop PC computers, tracks all incoming requests for laser safety information, range surveys, and laser system measurements. A product of this accurate tracking mechanism has been a significant reduction in customer response time. Also, comprehensive metrics for presentation to Armstrong Laboratory are now available.
- Laser Safety Consultations. During the period of performance of the TASC-AL/OEO contract, statistics regarding laser safety consultation work were assembled from the laser safety consultation database, and are presented in Table 1. These statistics do not include range survey work.

PROJECT OFFICER GROUP	NUMBER OF CONSULTS				MAN-HOURS LOGGED			
	FY 95	FY 96	FY 97	TOTAL	FY 95	FY 96	FY 97	TOTAL
USAF	61	90	93	244	139	1374	522	2035
SETA	0	5	35	40	0	5	77	82
TASC	0	24	49	73	0	181	1845	2026
TOTALS	61	119	177	357	139	1560	2444	4143

Table 1: Program 8 Consultation Tracking Statistics during TASC Period of Performance, 15 March 1995 - 30 June 1997.

- Completion of laser range surveys and reports for all currently operational CONUS and Alaska (PACAF) USAF and ANG air-to-ground ranges. Approximately forty ranges were surveyed, to include the Navy Range at Misawa, Japan.
- Establishment of the procedures and capabilities to produce timely Range Survey Reports "in-house," significantly reducing delivery time to AL/OEO customers.
- Production of an Internet presence for AL/OEO on the Brooks AFB World Wide Web (WWW) server. This includes a mechanism through which USAF and other Department of Defense personnel can request laser safety information via the Internet.
- Expertise in laser system measurements for the purposes of laser hazard characterization. A standard approach for performing and documenting laser system measurements is now in place.
- The characterization and hazard analysis of approximately 14 USAF laser systems.

Deliverable Items

Consultative Letters authored and delivered by TASC-Program 8 Team Members:

1) 7/10/96 - AL/OE-CL-1996-0171, Camp Grayling Air Gunnery Range Laser Safety Evaluation, Alpena, MI.
2) 7/10/96 - AL/OE-CL-1996-0172, Oscura/Red Rio Range Laser Safety Evaluation, Holloman AFB, NM.
3) 7/24/96 - AL/OE-CL-1996-0176, Camp Atterbury Range Laser Safety Evaluation, Camp Atterbury, IN.
4) 8/14/96 - AL/OE-CL-1996-0284, Smoky Hill Range Laser Safety Survey, Kansas Air National Guard, Salina, KS.
5) 8/16/96 - AL/OE-CL-1996-0288, USAF Dare County Range Laser Safety Evaluation, Seymour-Johnson AFB, NC.
6) 8/17/97 - AL/OE-CL-1996-0287, Ripsaw Range Laser Safety Evaluation, Misawa, Japan.
7) 9/9/96 - AL/OE-CL-1996-0316, Airburst Range Laser Safety Survey, Colorado Air National Guard, Peterson AFB, CO.
8) 9/12/96 - AL/OE-CL-1996-0317, Grand Bay Range Laser Safety Evaluation.
9) 9/25/97 - AL/OE-CL-1996-0323, Laser Safety Evaluation of 1.57um Laser System, US Army Night Vision Labs, Ft. Belvoir, VA.
10) 9/27/97 - AL/OE-CL-1996-0322, Indiana Air National Guard, Jefferson Range Laser Safety Evaluation, Jefferson Proving Ground, IN
11) 10/9/96 - AL/OE-CL-1996-0324, Hardwood Range Laser Safety Survey, Wisconsin Air National Guard, Volk Field ANGB, WI.
12) 10/9/96 - AL/OE-CL-1996-0344, Mississippi Air National Guard, Camp Shelby Range (202E and 201W) Laser Safety Evaluation.
13) 10/10/96 - AL/OE-CL-1996-0345, Melrose Range, Cannon AFB, NM.
14) 11/12/96 - AL/OE-CL-1996-0306, Utah Test and Training Range (UTTR) Laser Safety Survey, Hill AFB, UT.
15) 11/12/96 - AL/OE-CL-1996-0358, Laser Safety Evaluation of Ground Command Pointer, Model GCP-1B.
16) 11/12/96 - AL/OE-CL-1996-0359, Edwards AFB Test Range Laser Safety Survey, Edwards AFB, CA.
17) 12/18/96 - AL/OE-CL-1996-0372, Georgia Air National Guard, Townsend Range Laser Safety Evaluation, Townsend, GA.
18) 1/9/97 - AL/OE-CL-1996-0385, Nellis Range 74 Laser Safety Evaluation, Nellis AFB, NV.
19) 1/9/97 - AL/OE-CL-1996-0390, Nellis Range 62 Laser Safety Evaluation, Nellis AFB, NV.
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22) 1/9/97 - AL/OE-CL-1996-0394, Nellis Range 75 Laser Safety Evaluation, Nellis AFB, NV.

23) 1/9/97 - AL/OE-CL-1996-0384, Nellis Range 76 Laser Safety Evaluation, Nellis AFB, NV.
24) 1/9/97 - AL/OE-CL-1996-0387, Nellis Range 65 Laser Safety Evaluation, Nellis AFB, NV.
25) 1/9/97 - AL/OE-CL-1996-0386 Nellis Range 71 Laser Safety Evaluation, Nellis AFB, NV.
26) 1/27/97 - AL/OE-AL/OE-CL-1996-0395, Laser Safety Evaluation, FLIR-2000 Illuminator.
27) 2/7/97 - AL/OE-CL-1997-0032, Hazard Assessment of the AC-130U Gunship Laser Target Designator/ Rangefinder.
28) 2/25/97 - AL/OE-CL-1997-0035, Puerto Rico Air National Guard, Camp Santiago Laser Safety Evaluation, Salinas, Puerto Rico.
29) 3/27/97 - AL/OE-CL-1997-0057, Reflectance Measurements of Reflective Sheeting Samples.
30) 4/1/97 - AL/OE-CL-1997-0063, Laser Hazard Evaluation of Automated Laser Scoring System (ALSS) LITTON P3 NT-112 Laser.
31) 4/11/97 - AL/OE-CL-1997-0065, Texas Air National Guard, McMullen Range Laser Safety Evaluation.
32) 4/16/97 - AL/OE-CL-1997-0067, Range Laser Safety Evaluation, Eglin AFB, FL.
33) /16/97 - AL/OE-CL-1997-0068, Missouri Air National Guard, Cannon Range Laser Safety Evaluation, Laquey, MO.
34) 5/7/97 - AL/OE-CL-1997-0075, Pennsylvania Air National Guard, Ft. Indiantown Gap Weapons Range Laser Safety Evaluation Supplement for Firing Point Range 24B.
35) 5/23/97 - AL/OE-CL-1997-0114, Goldwater Range Laser Safety Survey-East Tactical Range, Luke AFB, AZ.
36) 5/23/97 - AL/OE-CL-1997-0112, Goldwater Range Laser Safety Survey-North Tactical Range, Luke AFB, AZ.
37) 5/23/97 - AL/OE-CL-1997-0113, Goldwater Range Laser Safety Survey-South Tactical Range, Luke AFB, AZ.
38) 5/23/97 - AL/OE-CL-1997-0116, Cobra Ball Big Safari Laser Health Hazard Evaluation Review.
39) 5/23/97 - AL/OE-CL-1997-0115, Arnold AFB Lab/Range Laser Safety Evaluation, Arnold AFB, TN.
40) 5/30/97 - AL/OE-CL-1997-0130, Pennsylvania Air National Guard (PaANG), Ft. Indiantown Gap Weapons Range Laser Safety Evaluation, Annville, PA.
41) 6/6/97 - AL/OE-CL-1997-0131, Laser Safety Assessment of the Air Commander's Pointer, Model 2A (ACP-2A).
42) 6/24/97 - AL/OE-CL-1997-0133, Laser Safety Evaluation of the Special Operations Forces Laser Marker (AN/PEQ-1 SOFLAM).

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2) 11/11/95 - “Draft” Laser Safety Evaluation of Eielson AFB Laser Ranges.
3) 1/1/96 - “Draft” Laser Safety Evaluation of Mountain Home AFB Laser Ranges.

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2) 23 - 24 Apr 1997: "Laser Range Safety (A Two Day Course)", AFSOC Laser Safety Course, Hurlburt Field, FL.
3) 27 - 29 Oct 1996: "Laser Safety Course for Range Officers" and "LANTIRN - Lockheed-Martin Measurements/Hazard Analysis, Laser Systems Safety Working Group and Range Commander's Council Meetings, Ocean City MD.

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Acronyms

AAVP	Advanced Aircrew Vision Protection
ADSPEC	Advanced Dye Spectacles
AFOSR	Air Force Office of Scientific Research
ALFA	Advanced Laser Filter for Aircrew
AL/OEO	Armstrong Laboratory - Optical Radiation Division
AMPS	Automated Mounting and Positioning System
ATD	Advanced Technology Demonstration
AVS	Advanced Visual Systems
CAD	Computer-Aided Design
CCD	Charge Coupled Device
CRT	Cathode Ray Tube
CW	Continuous Wave
DB	Database
DRad	Directed Radiator
ED_{50}	Estimated Dose for 50% Occurrence
ILPEM	Integrated Laser Personnel Effects Model
IOVS	Investigative Ophthalmology & Visual Science
IR	Infrared
LASED	Laser Aircrew Safety & Education Demonstrator
LEP	Laser Eye Protection
LIB	Laser Induced Breakdown
LSA	Logistics Support Analysis
MIT	Massachusetts Institute of Technology

Acronyms (continued)

MVL	Minimal Visible Lesion
OCT	Optical Coherence Tomography
OD	Optical Density
OE/LASE	Optics, Electronics, and Laser Application Science and Engineering
OR:S&C	Optical Radiation: Susceptibility and Countermeasures
OSADS	Optical Signature, Acquisition, and Detection System
PEATS	Protective Eyewear Automated Test System
PIKL	Pulsed Impulsive Kill Laser
QFD	Quality Functional Deployment
ROM	Rough Order of Magnitude
SEI	Software Engineering Institute
SPEX	Spectrometer manufacturer
SRI	Scanning Radiometric Imager
Ti	Titanium
TR	Technical Report
TTD	Technology Transfer Document
TTP	Technology Transition Package
USP	Ultrashort-Pulse
WARDOVE	Wideband Attenuating Reflective Dielectric Out-of-Band Visor Evaluation
WST	Weapons System Trainer
YA	Human Systems Program Office
Z-SCAN	Technique for measuring nonlinear optical properties of materials